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SOFT X-RAY IMAGING SYSTEM FOR IMPROVING QUALITY CLASSIFICATION OF FRUITS AND VEGETABLES: A REVIEW

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ABSTRACT

India is the second largest producer of vegetables (ranks next to China) and first in fruit production in the world. Consumers are now more conscious about quality and source of their foods. The term quality defines as "Degree to which a set of inherent characteristics fulfills requirements" (ISO 9000:2005). To determine the quality of food materials non-destructively is a difficult task, numerous methods are available but these methods are in destructive form. In recent years, non-destructive methods of quality evaluation have gained momentum and considerable attempts have been made to develop them, among these techniques X-ray and computed tomography imaging techniques are few of them which are gaining popularity now days in various fields of agriculture and food quality evaluation. Due to low penetration power and ability to reveal the internal density changes soft X-rays are more suitable to be used in fruits. Commercial application of these techniques will be beneficial for the consumer as well as the producer to get uniform high-quality products. In this article, literatures on the applications of soft x-ray imaging system in fruits and vegetables are briefly reviewed.

KEYWORDS: Non-Destructive, Internal Defects, Quality, Fruit, Soft X-Ray Imaging

INTRODUCTION

Due to wide range of adaptability, high nutritive value, and delicious taste and excellent flavor; fruits are very popular. India's fresh fruits and vegetables export was estimated 2437.1157 Rs. Crs in 2007-2008.

Researchers have been working to find techniques for evaluating internal quality attributes of agricultural and food products non-destructively. Growing consumer awareness in the international markets pose stringent quality measures on agricultural produce exported from India. Internal qualities include texture (firmness, crispness, juiciness), nutrition (carbohydrates, proteins and vitamins) and defects like pest infestation, internal cavity, water core, frost damage, rotten, spongy tissues are difficult to access by visual appearance hence there is a need for technology that can determine the internal quality parameters of the produce. The automatic inspection of quality in the agro-industry is becoming of paramount importance in order to decrease production costs and increase quality standards. X-ray imaging is one of the most prominent techniques for medical diagnostics. Besides medical imaging, there are many applications of X-rays such as checking luggage at airport, inspecting industrial components, security etc. Use of X-rays in inspection of agricultural commodity is still in primary stage.

In this paper, applications of soft X-ray in quality classification of fruits and vegetables, quality components of fruits and vegetables and non–destructive technologies available for evaluating them are review briefly.

NON –INVASIVE INSPECTION TECHNIQUES

In recent years, X-ray based systems have increasingly used as a research tool for the detection of internal defects in agricultural products. Techniques such as X-ray imaging, Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Near Infra red and ultrasound have been explored for non-destructive evaluation of indicators not visible on the surface of variety of agricultural products.

Nimesh *et al.,* 1993 have developed an image analysis system consisting of an illumination chamber, colour camera, frame grabber, and microcomputer to evaluate the colour of stonefruit. Defects were grouped into four categories: slight defects, more serious defects by sorting Jonagold apples based on the presence of defects using a multi-spectral vision system including four wavelength bands in the visible/NIR range leading to the rejection of the fruit and recent bruises (Kleynen *et al*., 2004). A machine vision system and an algorithm based on ultraviolet imaging was developed by Al-Mallahi *et al*., 2010 to detect potato tubers on the potato harvester and about 98.79% of the tubers and 98.28% of the clods were detected successfully. Khoshroo *et al*., (2009) obtained the images by Magnetic Resonance Imaging (MRI) of Iranian important export cultivar of pomegranate Malase-e-Torsh were analyzed by texture analysis to determine Gray Level Co-occurrence Matrix (GLCM) and Pixel Run-Length Matrix (PRLM) parameters. Combination of 7 GLCM and 4 PRLM features resulted in mean accuracy of 98.33 % and the lowest type I and II errors. The classification accuracies were 100, 98.47, 100 and 95 % for semi-ripe, ripe, over-ripe and internal defects classes.

En-cheng Yang et al. (2006) tested the possibility of using X-ray to examine internal injuries of various fruit. The results demonstrate that the current technique is a useful tool for the non-destructive inspection of internal injuries of fruit, something which cannot be determined solely with the naked eye.

Yacob et al. (2005) compared x-ray and magnetic resonance imaging (MRI) methods applied in postharvest non-destructive detection. From the study, x-ray is a possible method to perform non-destructive detection because it is more convenient and less costly compared to MRI.

X-Ray Imaging

X-rays are produced when high-energy electrons strike a target material, typically Tungsten. An X-ray tube is similar in design to a light bulb, except that the electrons shedding from the heated filament are subjected to a high voltage, causing them to accelerate and strike the target at high energies. As these high energy electrons decelerate in the target material, electrons of target atoms are first excited to higher energy levels, and then decay to their ground states with the emission of X-ray photons. The size of the target area over which X-rays are generated is called the focal spot size, and has consequences for the characteristics of the imaging system. The X-rays themselves have two characteristics that are important in the operation of the X-ray machine; energy and current. The energy refers to the maximum energy that an X-ray photon can possess when exiting the tube (generally between 20 and 100 KeV for food inspection) and defines the penetrating power of the X-ray beam. The current, measured in mA, is associated with the number of X-ray photons being generated. The power supply has a maximum power (the product of the energy and the current) rating, and a balance is therefore required between the energy and current, which has consequences for the resulting image quality. The result of this power limitation is that most X-ray inspection systems are limited to less than 10 mA of current.

Cristiane *et al.* (2005) was arranged a set up to product digital images from an X-ray spectrum (Figure 1) in the range of 18 to 20 keV, where the primary images acquired were tested by a digital image processing routine for differentiation of speed, pulp, peel and injured zones in Mangoes CV Tommy Atkins.

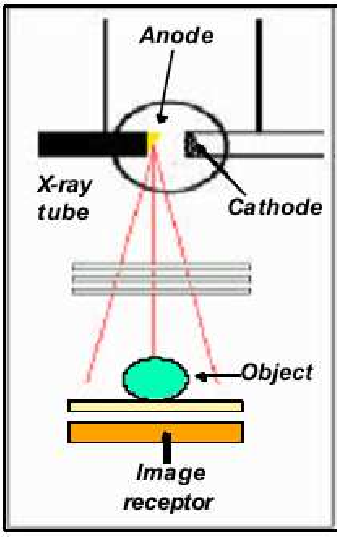

Figure 1: Arrangement for Production of Primary X-ray Images

X-ray images to find internal defects such as rind puffing in Oranges (Njorge et al., 2002). The emitted X-rays pass through the fruit and onto an X-ray scintillator. This device has a thin layer of luminescent material which allows a monochrome camera to capture the X-ray image for processing.

X-ray Analyses

X-ray was examined for its suitability for quality assessment of fruits. The shorter the wavelength, the larger is the penetration strength. Following a law of absorption, the intensity of the measured light after passing the sample is dependent on the initial intensity as well as on density and sample thickness of the absorber substance and its absorption coefficient (wavelength and material dependent). The high water content of vegetable products accounts for the largest portion of the absorption. Some internal disorders with negative effects on quality that should be detectable by X-ray techniques include cork spot, bitter pit, water core, and brown core for apple, blossom and decline, membranous stain, black rot, seed germination, and freeze damage for citrus, and hollow heart, bruises, and perhaps black heart for potato. Because the method is primarily dependent on the density of the tissue, not the chemical composition, the selectivity is limited (Tollner *et al.*1994). Three techniques for quality control are used: the 2-dimensional radiography well-known from medicine, the line scan method producing images when the product passes though a vertical plane of X-rays (known from baggage control at the airport), and Roentgen CT, which is also used in medicine. This method produces a 3-dimensional image, from which 2-dimensional information can be computed. Commercial routine is the detection of hollow heart in potato tubers (Nylund and Lutz 1950). The discovery of remaining pits in processed cherries or olives is important for the processing industry and has been the subject of investigations (Tollner *et al.*1994). Other publications cover the water content in apples (Tollner *et al.*1992), density changes during the ripening of tomatoes (Brecht *et al.* 1991), and insect infestation of pistachio nuts (Keagy *et al.* 1996). For separating out freeze-damaged citrus fruits, x-ray units are used in packaging facilities (Abbott *et al.* 1997). The visualization and analysis of the 3-dimensional (3D) cellular microstructure of a number of food products (aerated chocolate, mousse, marshmallow, and muffin) using X-ray micro-CT was reported

by Lim and Barigou (2004), and quantitative information was obtained on a number of parameters including spatial cell size distribution, cell wall-thickness distribution, connectivity, and voidage.

Pioneering work by Reyes *et al*. (2000) enabled the use of X-ray images to diagnose the mango seed weevil in intact mango fruit by evaluating distinct features of weevil-infested mango seeds. Fruit with various internal structures were used to qualitatively evaluate the potential of using X-rays, to reveal internal injuries caused by pests or physical impingement.

X-Ray Detection for Quality Classification

X-ray imaging is an established technique to detect strongly attenuating materials and has been applied to a number of inspection applications within the agricultural and food industries. X-rays are electromagnetic radiation ranging in wavelength from about 0.01 to 10nm. The shorter the wavelength of the x-ray the greater is its energy and its penetrating capacity. The shorter wavelengths closer to and overlapping the gamma rays are called hard x-rays. Electromagnetic waves with wavelengths ranging from 0.1 to 10 nm with corresponding energies of about 0.12 to 12 keV are called soft X-rays. Due to low penetration power and ability to reveal the internal density changes soft X-rays are more suitable to be used on agricultural products. Neethirajan *et al.* (2007) reported that the soft X-ray method was rapid and took only 3–5 s to produce an X-ray image.

The first X-ray detector was a sheet of paper coated with barium platinocyanide used by Roentgen in 1895. The paper fluoresced when impacted by X-rays, and led to their initial discovery. Since that time, many different materials have been observed to react to the presence of X-rays and have led to many different types of detectors. Modern X-ray inspection units generally fall into one of three categories: film, linescan machines, and direct detection semiconductor materials. Of these, film is the most widely used because of its high resolution and dynamic range. It is used for quality inspection of many food products other than medical and dental purposes.

Conventionally, there are two methods to acquire X-ray image. The first method is that the inspected object is fixed and the linescan sensor is moved with a constant speed within the exposure range of the X-ray source tube. The second method is that both X-ray source tube and linescan sensor are fixed and let the object move through the inspection zone.

For X-ray imaging, the photocathode is overlaid with a material that fluoresces in the presence of X-rays, converting the incident X-ray photons into visible light. A variation on X-ray linescan imaging that allows three dimensional images is computed axial tomography, or CT imaging. An X-ray source rotates around the sample with detectors positioned opposite the source. Multiple ‘‘slices’’ are progressively imaged as the sample is gradually passed through the plane of the X-rays. These slices are combined using a mathematical procedure known as tomographic reconstruction to form a three dimensional image. Helical or spiral CT machines incorporate faster computer systems and advanced software to process continuously changing cross sections. As the sample moves through the X-ray circle, three dimensional images are generated that can be viewed from multiple perspectives in real time on computer monitors.

Practical application of X-ray imaging in quarantine inspection to prevent propagation of alien insect pests in imported fruits is still unavailable. The first step to identify insect infestation in fruit by X-ray imaging technique is image acquisition. This is followed by the image segmentation procedure, which can locate sites of infestation. Since the grey level of X-ray images depends on the density and thickness of the test samples, the relative contrast of infestation site to

the intact region inside a typical fruit varies with its position. To accurately determine whether a fruit has signs of insect infestation Joe-Air Jiang *et al*., (2008) developed an adaptive image segmentation algorithm based on the local pixels intensities and unsupervised thresholding algorithm for several types of fruit such as citrus, peach, guava, etc. Analyses were performed using the developed algorithm on the X-ray images obtained with different image acquisition parameters. Fruit containing high amounts of water have been deemed unsuitable for X-ray imaging. En- Cheng Yang *et al*., (2006) tested the possibility of examining internal injuries of various fruit using digitized X-ray imaging analysis. The digitalized X-ray images showed that this technique can detect injuries caused by *B. dorsalis* at as early as 3 days after implantation of eggs in some fruits.

Cheng-Long Chuang *et al*., (2011) presented a new automatic and effective quarantine system for detecting pest infestation sites in agricultural products, e.g. fruits. This work integrated mechanical design, mechatronics instrumentation, X-ray and charge-coupled device (CCD) image acquisition devices, LabVIEW-based analysis and control software, and image diagnosis algorithms into the automatic X-ray quarantine scanner system.

Nachiket *et al*., (2007) used a soft X-ray digital imaging system to acquire radiographs of pecans. Schematic of typical equipment set up is shown in Figure 2. The equipment used consists of an X-ray tube, solid-state digital X-ray camera, computer, digital frame grabber, data acquisition and control card, along with appropriate software. The equipment has an X-ray tube capable of operating from 4 to 50 kVp with maximum current of 1 mA. X-rays generated at a tungsten anode pass through a 127-µm thick beryllium window with a diverging cone angle of 25˚. The X-ray spot at the window exit is a 76 µm×93µm oval. The solid-state digital X-ray camera positioned below the target sample, served as detector. The camera was constructed with a two-dimensional photodiode array of 1024×1024 pixels on 48-µm center-center spacing, giving a detector area of 49.2mm×49.2 mm. A data acquisition and control card was mounted on the computer for X-ray tube control. Peak voltage and current to the X-ray tube were software controlled.

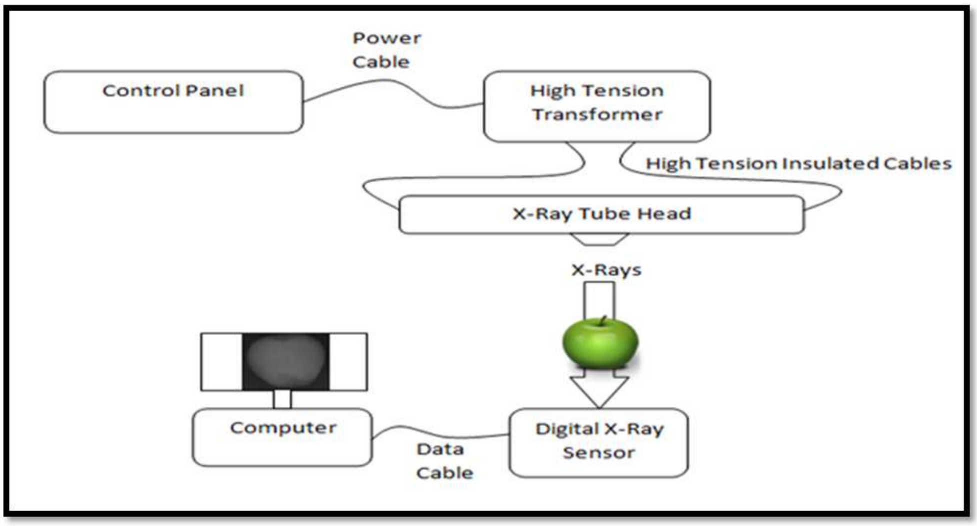

Figure 2: Schematic of X-ray Imaging Equipment

International conference (JECFI) organized by World Health Organization (WHO), the United Nations Food and Agriculture Organization (FAO), and the International Atomic Energy Agency (IAEA) reported "NO toxicological hazard is observed in any 10 kGy irradiation food**"** in 1981**.** From this report, it became obvious that there is no problem in microbiological safety, and nutriological qualification of irradiated food. The irradiation sterilization is conducted for

preventing spices and dry foods from injurious insects, bacteria and rodents in foreign countries instead of chemicals; it is being used for germination control of potatoes in Japan. It is said that the utilization for those purposes are good for environmental conservation. Based on these results, radiation is being indispensable for secure food because of sterilization. From this, a purpose of this study is establishment of technology to detect internal quality by a low energy soft X-ray which is able to be considered as a safety light.

Image Processing by Using Soft X-Ray

En-Cheng Yang *et al*. (2006) concluded that although injuries to fruit created by an insect's ovipositor may be too tiny to be detected by X-ray image analysis, tunnels created by larvae in infested fruit provide a good contrast on the images and are easily detected. The shape of the injury tunnels obviously differs from the internal structures of the fruit, and in addition to the contrast of the image, the density contours showed remarkable uneven lines or broken areas, indicating that the areas had been damaged by pests and the density had changed. More-advanced programming of image processing in order to detect injury tunnels, based on changes to the density of the flesh of the fruit, will improve detection success. Further development of this technology may offer an efficient and accurate inspection tool to determine infestations for imported commodities and to sort clean fruit prior to export.

Mathenker S. K. (2010) study deals with the automatic insect damage detection. Among machine vision techniques x-rays have distinct advantages in non-destructive food inspection. X-rays can look inside objects without breaking them apart, and alert us if the product is defective. These studies also suggest that increased emphasis on x-ray machine vision applications is due to the inability of human vision and other machine vision systems to identify the internal defects. Typical machine vision inspection systems involve acquiring an image and then segmenting the objects of interest by using various software techniques including thresholding. The quality of the acquired digital image plays an important role in machine vision applications, and it depends on imaging system components, objects, background, lighting, and noise.

Joe-Air Jianga et al. (2006) had been established the optimum parameters (Table 1) for some familiar imported/exported fruits via many experiments and equipped in the system database. Therefore the optimum parameters will be set automatically by this program after choosing the type of the inspected fruit by operator.

Table 1: The Optimum Parameters for Some Familiar Imported/Exported Fruits

Type of Fruit	Voltage (kV)	Current (μA)	Exposure Time (s)
Guava	75	125	0.12
Pitaya	75	125	0.12
Pear	75	125	0.12
Apple	75	125	0.12
Peach	65	125	0.12
Mango	75	125	0.12
Sunkist	70	125	0.12

Palou et al., (2007) presented a new automatic and effective quarantine system for detecting pest infestation sites in agricultural products, e.g. fruits. This work integrated mechanical design, mechatronics instrumentation, X-ray and charge-coupled device (CCD) image acquisition devices, LabVIEW-based analysis and control software, and image diagnosis algorithms into the automatic X-ray quarantine scanner system. Based on the LabVIEW development platform, a friendly graphical user interface (GUI) was designed for assisting the operations of quarantine scanner system.

Experimental results show that the X-ray quarantine scanner and pest infestation detector are able to locate the infested sites with highly successful rate up to 94% on the 4th day after eggs implanted.

Yanniotis et al. (2011) study the potential of X-ray imaging for detecting pistachios with kernel necrotic (KN) spots. X-ray images of whole pistachios were compared with colour pictures of the same nuts taken after the kernel was opened by splitting it in two. The necrotic spots appear in the X-ray images as darker gray areas of almost round shape. Also, pistachios with KN spots contained about 60 times more aflatoxin than healthy ones in an aflatoxin contaminated sample.

DEFECTS IN FRUITS AND VEGETABLES

Internal defects like internal cracks, internal core, internal discoloration, insect damage (weevil), borer, black heart, inside spongy tissue, etc. are generally found in most of the fruits and vegetables.

Mango

Non-edible sour patch developed in the mesocarp of mango fruit is broadly termed spongy tissue, (Weevils) insect injury or Larva Feeding injury, minor decay attack, shriveling, internal discoloration and internal lesions are the common defects found in mango fruits. Hindi Khassa (Jelly pulp or jelly seed) is common in ripe or over-ripe Mango (USDA, 2007).

Pomegranate

Fruit cracking is the serious problem in pomegranate. Internal discoloration, browning of arils, rotting and insect damage are found in pomegranate.

Potato

Black heart, Hallow heart or Hallow heart with internal discoloration, internal browning, Black spot, Fusarium wilt – *Fusarium* spp. (stem–end browning), fungus, Net necrosis – Potato leafroll virus (discolored strands), Verticillium wilt – *Verticillium* spp., fungus (Cavities sometimes develop inside tubers) and chilling injuries are generally found in potato (Zitter and Loria, 2012).

Sapota

Internal cracks, Immaturity, rotting or fungal infected, borer and insect damages are generally found in sapota.

Brinjal: Borer, internal discoloration and insect injuries are found in Brinjal.

HAZARDS OF RADIATIONS

Some common effects of x-rays are: alteration in physical properties of material (metals can be made brittle, plastics can be made stronger, and transparency of materials can be altered in some semiconductors); chemical changes (mixture of N_2 and O_2 gases gives nitrogen oxides, ethylene gas to polyethylene); biological effects (killing living organisms, preserving foods, medical oncology. All electromagnetic radiations having energy of 15 eV or more can ionize atoms (Jha, 2010).

One of the major problems associated with use of x-rays is that high-energy electromagnetic radiations, like x-rays can ionize and kill biological cells. It is therefore mandatory to provide a shield between the radiation source and

people working in the vicinity. Equipment designed for radiography, therefore needs to fulfil functional as well as radiation safety requirement.

APPLICATIONS OF SOFT X-RAY

Many applications are reported to detect the presence of defects in various commodities like apples, mango, onion, pistachio nuts, almonds, pecans etc. (Diener *et al.* 1970, Han *et al.* 1992, Keagy *et al.* 1996, Casasent *et al.* 1998, Abbot 1999, Kim and Schatzki 2000, Casasent *et al.* 2001, Kim and Schatzki 2001, Halff and Slaugter 2004, Tollner *et al.* 2005, Kotwaliwale *et al.* 2007) X–ray with energy ranging from 15 to 80 kvp at various current levels has been reportedly used. However, higher energy of 100 kvp has been found not suitable for radiography of food products (Jha, 2010). The preliminary work done on soft x-ray imaging is mentioned in following Table 2.

Table 2: Summary of Soft X-Ray Image Processing Applications for Food Quality Evaluation

Commodity	Application	References
Mango Fruit	Quality Characteristics	Eufemio et al. (1999)
Mango	Quality Parameters	Jha et al. (2010)
Peach fruits	Internal Quality Detection	Yuichi *et al*.(2003)
Apple	Water core sorting system	Kim and Scatzki (2000)
Almonds	Detection of pinholes	Kim and Scatzki (2001)
Pecans	Quality determination	Kotwaliwale *et al*.(2007)
Potato	Detection of blemishes	Barnes *et al*.(2010)

The reviews suggest that there is not published work on complete automated Soft x-ray imaging to grade Mango, Pomegranate, Sapota, Potato and Brinjal based on internal defects as an integrated system.

CONCLUSIONS

The adaptation of Image Processing for quality evaluation of fruit is the area of greatest potential technology, as analysis can be based on a standard requirement in already automated controlled conditions. X-ray based imaging techniques are powerful tools for non destructive internal quality evaluation. The international markets for Mango, Pomegranate and Sapota are huge and growing, to conquer and to sustain these markets, there is a need for export of high quality products with no internal defects. The currently practiced methods such as sensory evaluation, colour sorting, size grading, and similar ones cannot effectively address the classification of internal blemish free whole produce. Nevertheless, necessity has motivated a considerable research effort in this field spanning many decades. Many researchers have devoted considerable effort towards the development of machine vision systems for different aspects of quality evaluation and sorting of agricultural products. As a result, new algorithms and hardware architectures have been developed for high-speed extraction of features that are related to specific quality factors of fruits. The low penetration power and ability to reveal the internal density changes make soft X-rays suitable to be used for fruits. Harmful effects of X-rays are definitely a cause of concern while using these techniques, but properly designed shielding can prevent human exposure. Improvements in technology have allowed X-ray detection of internal defects that were not possible in the past. These improvements can be expected to continue into the future.

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